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3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	SHIMADZU RESEARCH LABORATORY (EUROPE) LTD Wharfside Trafford Wharf Road Manchester M17 1GP
	Patents ADP number *(if you know it)*	7477280001 Rdes
	If the applicant is a corporate body, give the country/state of its incorporation	England, UK
4.	Title of the invention	CHARGED PARTICLE ENERGY ANALYSERS
5.	Name of your agent *(if you have one)*	MATHISEN, MACARA & CO.
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	The Coach House 6-8 Swakeleys Road Ickenham Uxbridge UB10 8BZ
	Patents ADP number *(if you know it)*	1073001
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MATHISEN, MACARA & CO.

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DUPLICATE

UK PATENT APPLICATION

APPLICANTS: SHIMADZU RESEARCH LABORATORY (EUROPE) LTD

SHORT TITLE: CM ANALYSER

FORMAL TITLE: CHARGED PARTICLE ENERGY ANALYSERS

APPLICATION NO:

FILED:

PRIORITY CLAIMED:

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CHARGED PARTICLE ENERGY ANALYSERS

This invention relates to charged particle energy analysers, particularly charged particle energy analysers having the capability to analyse simultaneously charged particles having a wide range of energies.

In charged particle optical systems various devices are available for analysing the spectrum of energies of beams of charged particles and these devices have been comprehensively described in various works on the subject of charged particle optics; see for example, "Principles of Electron Optics" by P.H. Hawkes and E. Kasper (Academic Press, New York) 1989, and a paper by D. Roy and D. Tremblay, Rep Prog Phys. **53**, 1621 (1990). In many applications, such as Auger electron spectroscopy of surfaces, the range of energies of interest in a single spectrum can cover more than an order of magnitude. The conventional way of obtaining such a spectrum has been to scan through the energy range using a single detector. A faster technique is to use a multidetector or series of detectors to cover an extended range of energies and then to scan the complete range of the spectrum either continuously or in steps. It seems that in all the known electrostatic charged particle energy analysers, with the exception of the hyperbolic field analyser, the range of energies that can be analysed at any one time is small, the ratio of the energy range to the mean energy being typically less than 0.1. Therefore, if the stepping method is used the required number of steps is at least of the order of 10.

It is clearly advantageous to be able to analyse the whole energy spectrum simultaneously. The hyperbolic field analyser described by M. Jacka, M. Kirk, M. El Gomati and M. Prutton in Rev. Sci. Instrum, **70**, 2282 (1999) is able to do this. However, the hyperbolic field analyser has a substantially planar geometry and so suffers from the drawback that it is only able to analyse charged particles incident over a narrow angular range in azimuth.

According to a first aspect of the invention there is provided a charged particle energy analyser for analysing charged particles having a range of energies comprising, electrostatic focusing means having a longitudinal axis, a charged particle source for directing charged particles into an electrostatic focusing field generated, in use, by said electrostatic focusing means, and detection means for detecting charged particles focused by said electrostatic focusing means, wherein said electrostatic focusing field is defined by equipotentials which extend around said longitudinal axis and which increase monotonically in the longitudinal direction, whereby charged particles having different energies are brought to a focus by the electrostatic focusing field at discrete positions spaced apart from each other in the longitudinal direction.

Charged particle energy analysers according to this aspect of the invention have the capability to analyse simultaneously charged particles having a wide range of energies which are incident over the entire (360°) angular range in azimuth about the longitudinal axis or which are incident over one or more smaller azimuthal ranges.

This combination of features enables the energy spectra of charged particles to be measured more rapidly than has been possible using known analysers, and also enables angular information to be obtained.

Charged particle energy analysers according to the invention may also be used in a second-order focusing mode whereby charged particles having a relatively narrow range of energies, but incident of a relatively wide angular range in elevation relative to the longitudinal axis can be focused.

According to another aspect of the invention there is provided a charged particle energy analyser for analysing charged particles comprising, electrostatic focusing means having a longitudinal axis, a charged particle source for directing charged particles into an electrostatic focusing field generated, in use, by said electrostatic focusing means, and detection means for detecting charged particles focused by said electrostatic focusing means, wherein said electrostatic focusing means is defined by equipotentials which extend around said longitudinal axis and which increase monotonically in the longitudinal direction and said charged particle source directs said charged particles into said electrostatic focusing field over a predetermined angular range in elevation relative to said longitudinal axis, said predetermined angular range in elevation and the axial position of the charged particle source being selected for second-order focusing of the charged particles.

Embodiments of the invention are now described, by way of example only, with reference to the accompanying drawings, of which:

Figure 1 is a schematic, longitudinal sectional view of a first embodiment of a charged particle energy analyser according to the invention,

Figure 2 is an enlarged view of a part of the charged particle energy analyser of Figure 1, showing the contours of equipotentials in the range from 0 to -3200V, in steps of 200V,

Figure 3 is a schematic, longitudinal sectional view of a second embodiment of a charged particle energy analyser according to the invention,

Figure 4 is a schematic, longitudinal sectional view of a third embodiment of a charged particle energy analyser according to the invention operating in a second-order, axis-to-surface focusing mode, and

Figure 5 is a schematic, longitudinal sectional view of a fourth embodiment of a charged particle energy analyser according to the invention operating in a second-order, axis-to-axis focusing mode.

In the following description, the polarities of the applied potentials are chosen for the

analysis of negatively-charged particles, and in the embodiments of Figures 1 to 5 the charged particles are assumed to be electrons. It will, of course, be appreciated that positively-charged particles may be analysed by reversing the polarities of the applied potentials.

Referring now to Figures 1 and 2 of the drawings, the charged particle energy analyser has cylindrical symmetry about a longitudinal axis z-z. The analyser comprises a localised source of electrons 1 situated on that axis, an inner cylinder 2 of radius R_1 at ground potential, an outer cylinder 3 of radius $R_2 = 4R_1$ whose ends have axial coordinates $z = -3R_1$ and $15R_1$ to which is applied a potential drop that varies linearly from +1039.7V to -5198.6V at the left- and right-hand ends respectively, a first annular end disc 4 to which is applied a potential drop that varies from +1039.7V at its outer edge to the ground potential at its inner edge, a second annular disc 5 to which is applied a potential drop that varies from -5198.6V at its outer edge to the ground potential at its inner edge, and a detector 6 of electrons that forms a part of the outer surface of the inner cylinder 2 or conforms to a part of that surface. Figure 1 also shows some representative curved trajectories 7 of electrons that originate at the localised source 1 and are focused onto the detector 6 by the electrostatic focusing field created between the inner and outer cylinders 2,3. In this illustration, electrons having the initial energies 125,200,300,500,800,1250,2000 and 3000eV are focused at successive axial positions $z_1, z_2 \ldots z_8$ in the longitudinal direction.

In this example, the potentials applied to cylinders 2,3 are given by equation (1) below, where W = 346.57V (=250ln4). The potentials applied to the annular end discs 4,5 are also given by equation (1) and are non-linear. In practice, the annular end discs 4,5 may be made from a material of high electrical resistivity. Alternatively, instead of using a disc, the required potential drop could be implemented using a plurality of concentric, annular rings each maintained at a different uniform potential. The axial position of source 1 is $z_s = 1.85R_1$, the medial elevational launch angle $\bar{\theta}_s$ of the electron beam B is 0.472rad (27.04°) relative to the longitudinal axis z-z and the half-angle of the beam is 0.016rad (0.91°). The angular extent in elevation of the beam may be controlled by an aperture or apertures provided in a mask (not shown) located between the source 1 and the inner cylinder 2. The potential of the inner cylinder 2 is 0V and, in this embodiment, the beam is assumed to pass through a fine mesh or grid that covers the entrance region of the inner cylinder 2.

The properties of the analyser are of course unchanged if the applied potentials and the energies are scaled linearly together.

As already described, the potential applied to the outer cylinder 3 varies linearly from +1039.7V at the left hand end to -5198.6V at the right hand end. This linear variation in potential can be implemented by means of a cylinder 3 made from a material of high resistivity or, alternatively, the required potential may be simulated by means of a plurality of electrically conductive loops or rings, each of which is maintained at a

different uniform potential. The inner cylinder 2 which is maintained at ground potential may be made from electrically conductive material. The distribution of potential in the region between cylinders 2,3 is uniform as a function of azimuthal angle about the longitudinal axis z-z. The potential $\phi(r,z)$ can be expressed in terms of the radial and axial coordinates (r,z) by the expression:

$$\phi(r,z) = -Wz \ \ln r \ / \ \ln R_2 \tag{1}$$

Because an analytical solution to the equations of motion in the electrostatic field appear not to exist, the accurate CPO-2D program available on web site http://cpo.ph.man.uk has been used to solve Laplace's equation for various practical systems and to integrate the equations of motion to obtain particle trajectories.

Referring again to Figures 1 and 2, electrons emanating from source 1 on the longitudinal axis z-z are focused on the surface of the inner cylinder 2 after energy analysis and the electrons are detected there by a curved detector array 6 that conforms to or forms part of the surface of the inner cylinder 2.

As will be described in greater detail hereinafter, the electron beam B spans a predetermined angular range in azimuth about the longitudinal axis z-z. The angular range may be the entire (360°) azimuthal range or one or more smaller azimuthal ranges, and detector 6 may be so located and configured as to detect for electrons in one or more of these angular ranges. Detector 6 may take the form of a microchannel array detector or a microsphere plate detector or a position-sensitive resistive plate

detector or any other suitable form of detector.

In a particular embodiment, the charged particle source 1 comprises a target located on the longitudinal axis z-z and an irradiation device for directing radiation onto the target to generate charged particles. The irradiation device may, for example, be an electron gun and may be located within the inner cylinder 2.

In practice, the trajectories of charged particles having the same energy but different elevational angles may be subject to dispersion caused by their exposure to slightly differing field intensities in the region between the inner and outer cylinders 2,3, and this reduces the sharpness of the focused image. However, the axial position z_s of the source 1 and the medial, elevational launch angle $\bar{\theta}_s$ of the charged particle beam can be optimised to minimise the dispersive effect of the electrostatic field over the entire energy range of interest.

The axial position z_i of the image formed by charged particles of energy E_i can be expressed as:

$$z_i = c_o + c_2(\theta_s - \theta_0)^2 \ldots, \qquad (2)$$

where c_0 is the axial position of the image if there is no dispersion, c_2 is a constant, θ_0 is the elevational launch angle needed to bring the charged particles to a focus at the axial position c_0 when dispersion is present and θ_s is the launch angle of the trajectory of a charged particle within the beam.

The optimal condition exists when θ_0 is constant over the entire energy range of interest and in the embodiment described with reference to Figure 1 this condition is almost satisfied when z_s is set at $-1.85R_1$. Table 1 lists the resultant values of θ_0 and z_i obtained using these settings for eight different energies, namely 125eV, 200eV, 300eV, 500eV, 800eV, 1250eV, 2000eV and 3000eV. A suitable medial launch angle $\bar{\theta}_s$ is then 0.472rad (27.04°).

As can be seen from this Table, the values of θ_0 are approximately constant over the whole energy range, the slight inconstancy of θ_0 being less than the typical range of angles accepted from a source.

A plot of exemplary trajectories is shown in Figure 1, and these same trajectories are shown in Figure 2 on an enlarged scale together with the contours of selected equipotentials.

Table 1 also includes values of the relative energy dispersion Edz_i/dE and a set of energy resolutions ΔE that will now be defined.

It will be apparent from equation 2 above that the spread Δz_i in the axial position of an image at each energy E_i is given by the expression:

$$\Delta z_i = |c_2|(\Delta\theta_{max})^2 \qquad (3)$$

where $\Delta\theta_{max}$ is the maximum angular deviation of trajectories (in a given range) from θ_0 for that energy. This spread in axial position is approximately equivalent to an energy spread ΔE given by the expression:

$$\Delta E = 0.5 \Delta z_i \bigg/ \frac{dz}{dE} \quad , \tag{4}$$

where the factor 0.5 is used as an approximation to convert the base energy width to the width at half height of a peak. As will be clear from the values of ΔE listed in the last column of Table 1, the useful energy range in this example covers at least a factor of 10.

For the source position z_s that has been used ($-1.85R_1$) θ_0 is stationary (in fact a maximum) when the initial energy E is approximately 1000eV. It might be useful in practice to change the value of E for which θ_0 is stationary by varying z_s. This would give some control over the dependence of ΔE on E. In practice, adjustments of z_s may be facilitated by physically adjusting the axial position of the source 1 or by, in effect, axially translating the electrostatic field relative to the source by changing the axial position at which zero potential is applied to the outer cylinder.

Other parameters could be varied to make θ_0 more constant. In particular the linear variation of the voltage on the outer cylinder could be replaced by a slightly non-linear (but monotonically increasing) variation, the parameters of which would be adjusted to minimise the fluctuations in θ_0. Alternatively, the shapes of the electrodes could

be changed, for example by using conically-shaped electrodes in place of discs and cylinders.

The analyser described with reference to Figures 1 and 2 generates an electrostatic focusing field which is uniform as a function of azimuthal angle about the longitudinal axis. However, this need not necessarily be the case; alternatively, the field may have n-fold rotational symmetry about the longitudinal axis, where n is an integer. Such a field could be generated by replacing the inner cylinder with a tubular member having n-fold symmetry, such as a flat-sided electrode having a polygonal transverse cross-section. This configuration has the advantage that a detector can be readily located on one or more of the flat sides.

In another implementation of the invention, the outer cylinder is replaced by a curved axially symmetric plate to which a (possibly uniform) potential is applied and which is appropriately shaped to create monotonically increasing equipotentials such as the equipotentials generated by the inner and outer cylinders 2,3 of the embodiment described with reference to Figures 1 and 2.

In the embodiment of Figure 1, the inner cylinder 2 has a window or windows by which electrons are admitted to the electrostatic focusing field. The or each window is so dimensioned and shaped as to define a beam having the required angular range in azimuth, and is covered by a fine mesh or grid to help to eliminate edge effects.

The mesh could, for example, consist of a square array of holes or could be made from parallel wires extending in the longitudinal z direction that are stretched across the window. The shielding properties of both these types of mesh are known, as are the defocusing effects that the meshes produce. The defocusing is effectively equivalent to increasing the size of the source.

Alternatively, the angular range in azimuth could be defined by an aperture or apertures provided in a mask (not shown) located between the source 1 and the inner cylinder 2.

In some practical applications it might be more convenient to use an open window, having the form of a slot in the azimuthal direction. In another embodiment shown in Figure 3, electrons enter the electrostatic focusing field through an open slot in the inner cylinder 2' extending between the axial coordinates $z = 0.05R_1$ and $0.24R_1$. The outer cylinder 3' has a radius of $3R_1$ (in units of the radius of the inner cylinder) and extends between the axial coordinates $z = 0$ and $z = 10R_1$. A left-hand end is closed by a disc at ground potential. As before, the potentials applied to the outer cylinder and a right-hand end disc are given by equation (1), but where $W = 274.65V$ ($=250 \ln 3$). By application of the above-described analysis based on Equation 2 above, the optimal axial position of the source 1' is found to be $-1.8R_1$ and the optimal medial elevational launch angle $\bar{\theta}_s$ is found to be 0.476rad (27.25°). The results of this analysis are shown in Table 2, and some exemplary trajectories are illustrated in

Figure 3, where electrons having the initial energies 125eV, 200eV, 300eV, 800eV, 1250eV and 2000eV are focused at successive axial positions z_1, z_2 ....z_6 in the longitudinal direction. By comparing the data in Tables 1 and 2 it can be seen that the values of θ_0 vary less when the entrance aperture is open. This form of the analyser is however less suitable when second-order focusing is required, as will be discussed below.

Other positions of the electron source and the image are envisaged. The source and the image may both be located at the surface of the inner cylinder 2 (surface-to-surface focusing) or, alternatively, the source and the image may both be located on the longitudinal axis z-z (axis-to-axis focusing). Alternatively, the source could be located in a field-free region between the longitudinal axis z-z and the inner cylinder 2 and the image could also be located between the longitudinal axis and the inner cylinder 2 or radially outwards of the inner cylinder.

The source of electrons may, in effect, be a virtual source; in this case, the source directs electrons into the electrostatic focusing field from a location or locations offset from the longitudinal axis and includes suitable focusing means, which could be in the form of one or more conical lens, for example, for focusing electrons emitted from a real source (which may be located on-axis) at said location or locations.

Similarly, such focusing means may be used to focus electrons forming an image onto

one or more detector spaced apart from the image.

In another mode of operation, charged particle energy analysers according to the invention can be arranged to analyse charged particles in a relatively narrow energy band incident over a relatively wide angular range in elevation.

One of the main advantages of a conventional Cylindrical Mirror Analyser (CMA), as described, for example, by J.S. Risley in Rev. Sci. Instrum. **43**, 95 (1972) is that it can be operated with second-order focusing. That is, it is possible to find conditions for which the axial position z_i of the focus point has a dependence on the elevational launch angle θ_s of a charged particle of the form

$$z_i = c_0 + c_2(\theta_s - \theta_0)^2 + c_3(\theta_s - \theta_0)^3 + \ldots \tag{5}$$

where the second-order term is zero. The absence of the usual quadratic term implies that a wide range of angles θ_s can be accepted for a given energy resolution of the analyser, provided that the coefficient c_3 is not too large.

Figure 4 shows an embodiment of a charged particle energy analyser according to the invention operating in this second-order focusing mode.

Here, the dimensions of the analyser and the applied voltages are exactly the same as

for the analyser described with reference to Figure 3, but differs in that a fine mesh is placed across the entrance window in the inner cylinder 2' and in that the axial position z_s of the source 1' is $2R_1$. It is found by analysis that the quadratic term in Equation 5 becomes zero when E = 854eV and when the medial launch angle $\bar{\theta}_s$ = 0.622rad (35.6°). In this embodiment, the half angle of the beam is 0.05rad (2.86°).

In fact, a continuous spectrum of such conditions exists. For a given source position z_s (within some range) it is possible to find values of E and $\bar{\theta}_s$ that give second-order axis-to-surface focusing. Some results are shown in Table 3.

Second-order focusing may also be performed in the axis-to-axis mode, and this is shown in Figure 5. The dimensions of the analyser and the applied voltages are exactly the same as the analyser described with reference to Figure 4, but differs therefrom in that the axial position z_s of the source is $-R_1$. Again, a fine mesh is placed across the entrance window in the inner cylinder 2'. It is found by analysis that the quadratic term in Equation 5 becomes zero when E = 1345.5eV and the medial elevational launch angle $\bar{\theta}_s$ of the beam is 0.444rad (25.46°). In this embodiment, the half angle of the beam is 0.05rad (2.86°). Again a continuous spectrum of such conditions exists, as shown in Table 4.

As with the conventional CMA, a continuous spectrum of other modes of operation is possible and it is envisaged that second-order focusing might also be achievable

when the entrance window is open. It is also possible to find conditions for which the energy resolution is optimised for a particular narrow range of energies.

Table 1

E	θ_0	z_i	Edz_i/dE	ΔE
125	0.4674	1.455	0.855	0.22
200	0.4691	1.876	1.102	0.23
300	0.4703	2.349	1.380	0.23
500	0.4715	3.140	1.845	0.24
800	0.4722	4.136	2.430	0.37
1250	0.4719	5.416	3.182	0.51
2000	0.4704	7.262	4.267	1.41
3000	0.4679	9.429	5.540	4.34

Table 2

E	θ_0	z_i/R_1	Edz_i/dE
125	0.4760	1.46	0.780
200	0.4758	1.882	1.028
300	0.4762	2.354	1.318
500	0.4766	3.146	1.812
800	0.4766	4.142	2.460
1250	0.4758	5.422	3.329
2000	0.4740	7.267	4.622

Table 3

z_s/R_1	E	θ_0	z_i/R_1
-2	43.5	0.435	1.136
-1.5	123	0.471	1.483
-1	201	0.519	2.001
0	410	0.574	3.144
1	630	0.606	4.230
2	854	0.622	5.287
3	1082	0.635	6.328
4	1315	0.642	7.367

Table 4

z_s/R_1	E	θ_0	z_i/R_1
-2.5	1206	0.359	5.886
-2.0	1223	0.386	5.988
-1.0	1356	0.441	6.448
0.0	1556	0.494	7.102
1.0	1763	0.538	7.807
2.0	2009	0.573	8.630
3.0	2281	0.598	9.471
5.0	2862	0.631	11.35

CLAIMS

1. A charged particle energy analyser for analysing charged particles having a range of energies comprising,

electrostatic focusing means having a longitudinal axis,

a charged particle source for directing charged particles into an electrostatic focusing field generated, in use, by said electrostatic focusing means, and

detection means for detecting charged particles focused by said electrostatic focusing means,

wherein said electrostatic focusing field is defined by equipotentials which extend around said longitudinal axis and which increase monotonically in the longitudinal direction, whereby charged particles having different energies are brought to a focus by the electrostatic focusing field at discrete positions spaced apart from each other in the longitudinal direction.

2. A charged particle energy analyser for analysing charged particles comprising,

electrostatic focusing means having a longitudinal axis,

a charged particle source for directing charged particles into an electrostatic focusing field generated, in use, by said electrostatic focusing means, and

detection means for detecting charged particles focused by said electrostatic focusing means,

wherein said electrostatic focusing means is defined by equipotentials which

extend around said longitudinal axis and which increase monotonically in the longitudinal direction and said charged particle source directs said charged particles into said electrostatic focusing field over a predetermined angular range in elevation relative to said longitudinal axis, said predetermined angular range in elevation and the axial position of the charged particle source being selected for second-order focusing of the charged particles.

3. An analyser as claimed in claim 1 or claim 2 wherein said equipotentials are symmetrical about said longitudinal axis.

4. An analyser as claimed in any one of claims 1 to 3 wherein said equipotentials increase linearly in said longitudinal direction and increase logarithmically in the transverse direction.

5. An analyser as claimed in claim 1 or claim 2 wherein said electrostatic focusing means comprises inner and outer field defining means arranged concentrically about said longitudinal axis, said outer field defining means being maintained, in use, at a potential relative to said inner field defining means which increases monotonically in the longitudinal direction.

6. An analyser as claimed in claim 5 wherein said inner field defining means and said outer field defining means comprise an inner cylinder and an outer cylinder

respectively, wherein said inner cylinder is maintained, in use, at a uniform potential and said outer cylinder is maintained, in use, at potential increasing linearly in the longitudinal direction.

7. An analyser as claimed in claim 6 wherein said outer cylinder is made from electrically resistive material.

8. An analyser as claimed in claim 5 wherein said outer field defining means comprises a plurality of discrete field defining elements, each said element being maintained, in use, at a different respective potential with respect to said inner field defining means.

9. An analyser as claimed in claim 8 wherein each said field defining element has the form of a ring or loop.

10. An analyser as claimed in claim 8 wherein each said field defining element has the form of a hollow, truncated cone.

11. An analyser as claimed in claim 5 wherein said outer field defining means comprises a plurality of discrete field defining elements each being made from electrically resistive material and being maintained, in use, at a respective potential which increases monotonically in the longitudinal direction.

12. An analyser as claimed in claim 11 wherein each said element has the form of a cylinder.

13. An analyser as claimed in claim 11 wherein each said element has the form of a hollow, truncated cone.

14. An analyser as claimed in any one of claims 5 to 13 including first and second end elements located at opposite ends of said inner and outer field defining means in respective planes transverse to said longitudinal axis, each of said first and second end elements being maintained in use at a potential relative to said inner field defining means which varies non linearly in the transverse direction.

15. An analyser as claimed in claim 14 wherein each said end element is maintained in use at a potential relative to said inner field defining means which varies logarithmically in the transverse direction.

16. An analyser as claimed in claim 15 wherein each said element is made from electrically resistive material.

17. An analyser as claimed in claim 14 or claim 15 wherein each said element comprises a plurality of concentric electrically conductive rings each being maintained, in use, at a different respective potential.

18. An analyser as claimed in claim 1 or claim 2 wherein said electrostatic focusing means is so configured that the distribution of potential in said electrostatic focusing field is uniform as a function of azimuthal angle about said longitudinal axis.

19. An analyser as claimed in claim 1 or claim 2 wherein said electrostatic focusing means is so configured that the distribution of potential in said electrostatic focusing field has n-fold rotational symmetry about said longitudinal axis, where n is an integer.

20. An analyser as claimed in claim 5 wherein said inner field defining means and/or said outer field defining means has n-fold rotational symmetry about said longitudinal axis, where n is an integer.

21. An analyser as claimed in claim 20 wherein said inner field defining means comprises a plurality of flat side surfaces having n-fold rotational symmetry about said longitudinal axis, where n is the number of said surfaces.

22. An analyser as claimed in claim 21 wherein said charged particles are brought to a focus at one or more of said side surfaces and said detection means is located at said one or more side surfaces to detect the focused charged particles.

23. An analyser as claimed in any one of claims 5 to 20 wherein said charged

particles are brought to a focus at said inner field defining means and said detection means is located at and conforms to said inner field defining means to detect the focused charged particles.

24. An analyser as claimed in any one of claims 5 to 17 wherein said charged particles are brought to a focus at said longitudinal axis and said detection means is located on said longitudinal axis to detect the focused charged particles.

25. An analyser as claimed in any one of claims 1 to 24 wherein said charged particle source is located on said longitudinal axis.

26. An analyser as claimed in claim 25 wherein said charged particle source comprises a target located on said longitudinal axis and means for directing radiation onto said target whereby to generate said charged particles.

27. An analyser as claimed in any one of claims 5 to 17 wherein said charged particle source comprises a target located on said longitudinal axis and means for directing radiation onto said target whereby to generate said charged particles, said target and said means for directing radiation being located within said inner field defining means.

28. An analyser as claimed in claim 26 or claim 27 wherein said means for

directing radiation is an electron gun.

29. An analyser as claimed in any one of claims 1 to 28 wherein said charged particle source directs charged particles into said electrostatic focusing field over a predetermined angular range in azimuth about said longitudinal axis.

30. An analyser as claimed in claim 29 wherein said charged particle source directs said charged particles into said electrostatic focusing field over the entire (360°) angular range in azimuth.

31. An analyser as claimed in any one of claims 1 to 28 wherein said charged particle source directs charged particles into said electrostatic focusing field over two or more discrete angular ranges in azimuth about said longitudinal axis.

32. An analyser as claimed in claim 5 wherein said charged particle source directs charged particles into said electrostatic focusing field over one or more predetermined angular range in azimuth about said longitudinal axis, said charged particles being admitted to the electrostatic focusing field by one or more windows in the inner field defining means.

33. An analyser as claimed in claim 32 wherein the or each said window has the form of an electrically conductive grid or mesh.

34. An analyser as claimed in any one of claims 1 to 28 wherein said charged particle source directs charged particles into said electrostatic focusing field over two or more predetermined angular range in azimuth about said longitudinal axis, and said detection means is so configured and arranged as to detect charged particles derived from each said angular range.

35. An analyser as claimed in any one of claims 1 to 34 wherein said detection means comprises one or more detector selected from a multi channel array detector, a microsphere array detector and a position-sensitive resistive plate detector.

36. An analyser as claimed in claim 35 wherein said one or more detector incorporates a phosphor-coated detection plate.

37. An analyser as claimed in any one of claims 1 to 36 including means for adjusting the axial position of said charged particle source.

38. An analyser as claimed in claim 5 including means for adjusting said potential whereby to vary the axial position of the electrostatic focusing field relative to said charged particle source.

39. An analyser as claimed in any one of claim 1 wherein said charged particle source includes aperture means for directing charged particles onto said electrostatic

focusing field over a predetermined angular range in elevation relative to said longitudinal axis.

40. An analyser as claimed in claim 39 wherein said predetermined angular range in elevation and the axial position of said charged particle source and/or the axial position of the electrostatic focusing field can be adjusted for second-order focusing of charged particles having a relatively narrow range of energies.

41. An analyser as claimed in any one of claims 1 to 40 wherein said charged particle source directs said charged particles from a location or locations offset from said longitudinal axis.

42. An analyser as claimed in claim 41 wherein said charged particle source includes means for focusing charged particles at said location or locations.

43. An analyser as claimed in any one of claims 5 to 17 wherein said charged particle source and said detection means are both located between said longitudinal axis and said inner field defining means.

44. An analyser as claimed in any one of claims 5 to 17 wherein said charged particles are brought to a focus at said inner field defining means and said detection means comprises a detector located radially inwards or radially outwards of the inner

field defining means and means for focusing said focused charged particles onto the detector.

45. An analyser as claimed in any one of claims 5 to 17 wherein said charged particle source directs said charged particles from a location or locations at said inner field defining means and said charged particles are brought to a focus at said inner field defining means.

46. An analyser as claimed in claim 45 wherein said charged particle source includes means for focusing charged particles at said location or locations.

47. An analyser as claimed in claim 5 wherein said outer field defining means comprises a curved plate having rotational symmetry about said longitudinal axis.

48. An analyser as claimed in claim 47 wherein said curved plate is maintained at a uniform potential.

49. An analyser as hereinbefore defined with reference to the accompanying drawings.

ABSTRACT

CHARGED PARTICLE ENERGY ANALYSERS

A charged particle energy analyser (Figure 1) comprises a source of electrons 1 and inner and outer cylinders (2,3) arranged concentrically about a longitudinal axis (z-z). Electrical potential applied to the outer cylinder (3) creates an electrostatic field between the cylinders (2,3) defined by equipotentials which are symmetrical about the longitudinal axis z-z and increase linearly in the longitudinal direction. Electrons having different energies are focused by the electrostatic field at discrete positions spaced apart from each other in the longitudinal direction. The analyser may operate in the second-order focusing mode.

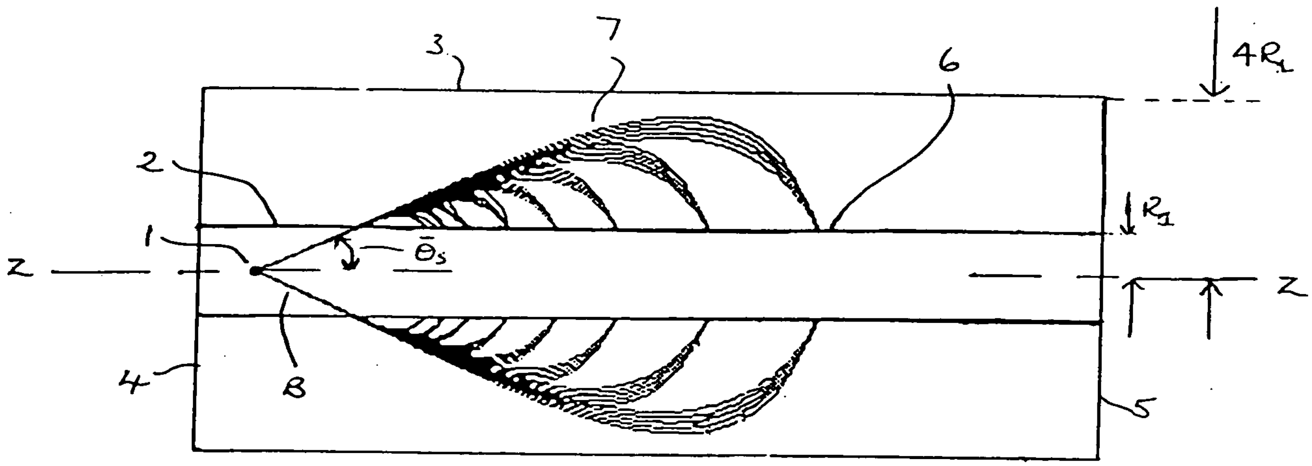

Figure 1

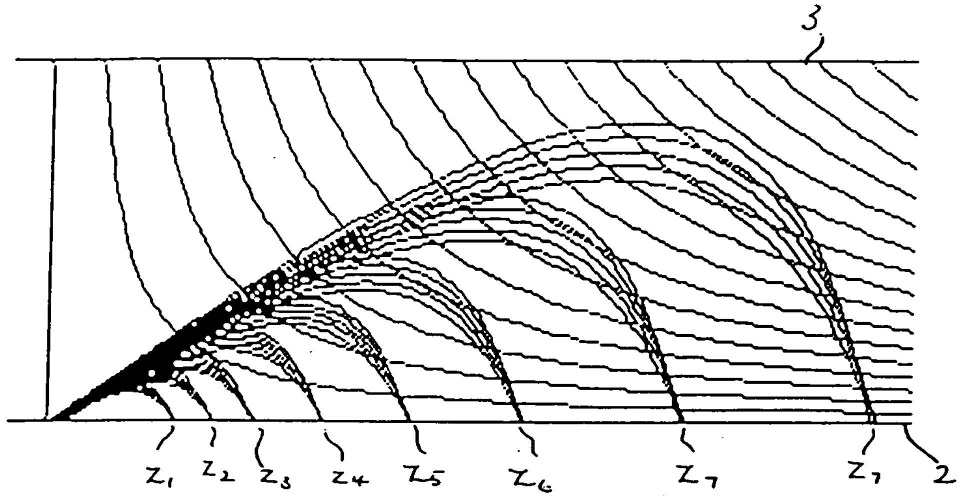

Figure 2

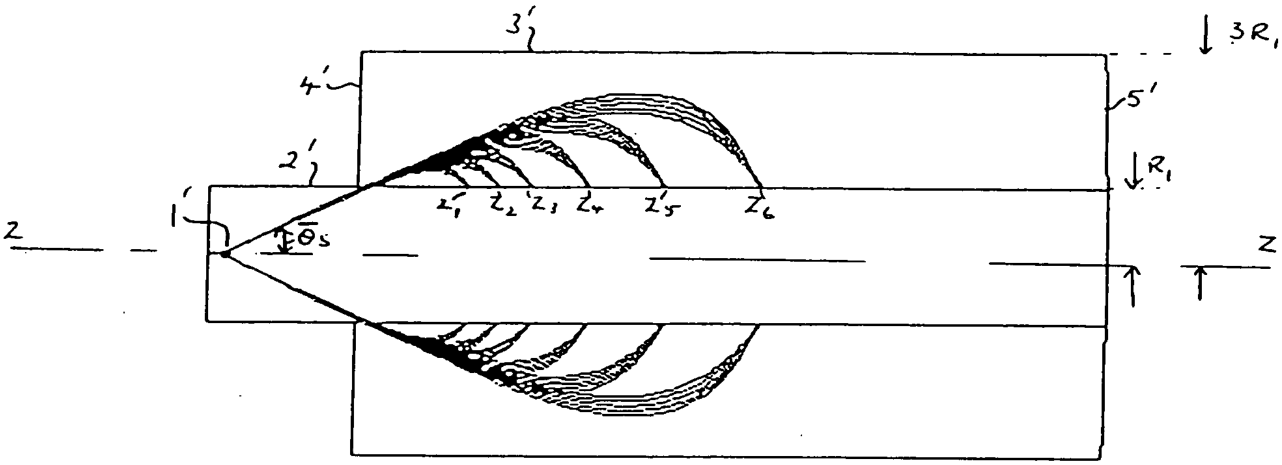

Figure 3

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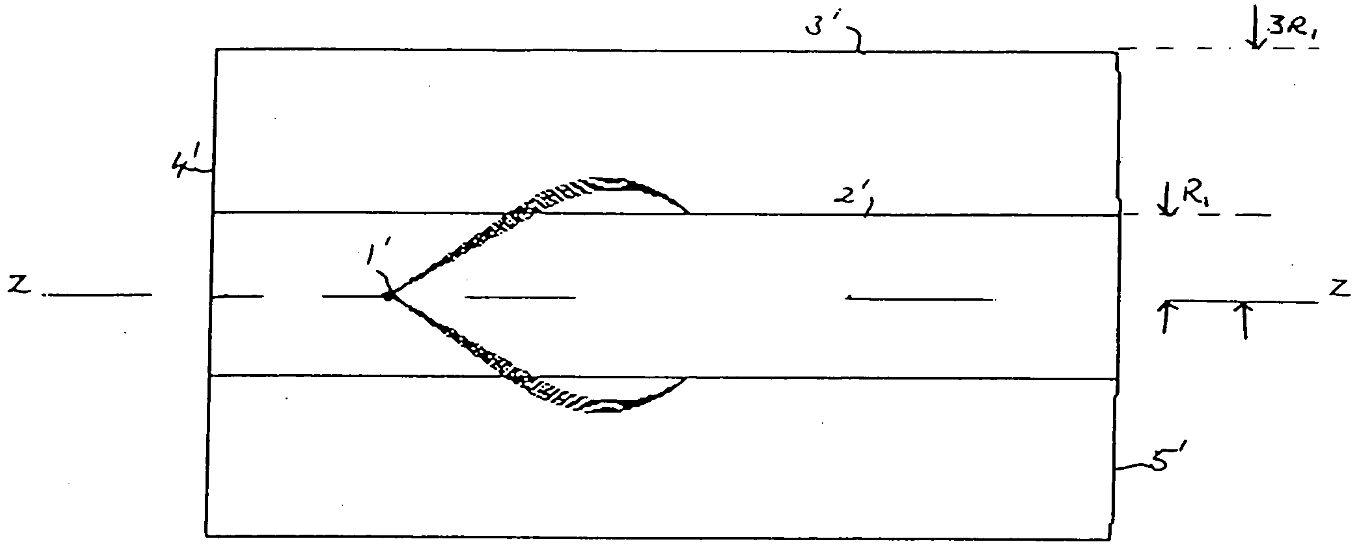

Figure 4

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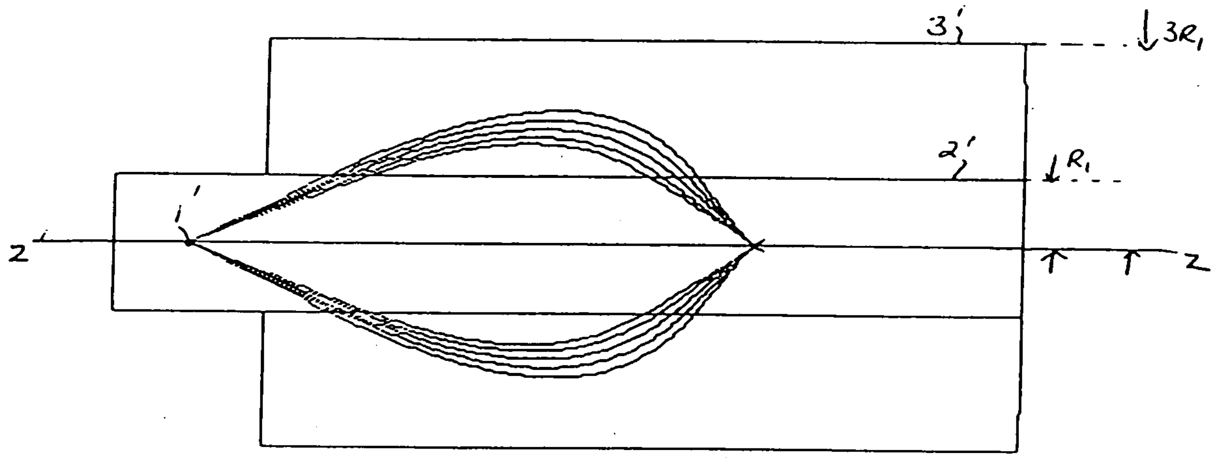

Figure 5